U. S. NAVAL AIR DEVELOPMENT CENTER

JOHNSVILLE, PENNSYLVANIA

Aviation Medical Acceleration Laboratory

NADC-MA-6215 26 December 1962

Flame Contact Studies

I. Apparatus and Method for Determination of Heat Transfer through Fabric during Flame Contact

Bureau of Medicine and Surgery
Subtask MR005.13-1005.1 Report No. 28
Bureau of Naval Weapons
WepTask RAE 20J 010/2021/F012 10 002
Problem Assignment No. J44AE22-2

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SUMMARY

A series of studies of heat transfer through lightweight fabric of a new heat-resistant, non-flammable synthetic fiber in contact with fuel flames serves to illustrate a system for determination of such thermal behavior. In this paper the method and data are given for ascertaining the destruction temperature of the fabric, its resistance to heat transfer, and the insulation effect of air-spaces between two layers of the material.

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INTRODUCTION

Standard flame tests of fabrics are directed toward determination of characteristics such as glowing, flaming and charring of the material (1). They do not provide measurements of resistance to heat transfer through the fabric before destruction. Heat transmission measurements are normally made only with conduction or radiation heating and at relatively low temperatures. This paper presents a description of an apparatus designed for utilization in flame contact studies of heat transfer by a method especially developed for use with fabric but which is readily applicable to a wide range of materials.

DESIGN

The apparatus is shown schematically in Fig. 1. It consists of a Meker burner (B) equipped with a pilot light and attached to a propane-propylene gas source. The air-intake regulator cuff is removed so that the air supply remains maximal and constant. A flowmeter (F) permits setting the gas flow at a fixed rate so that the flame is reproducible. A movable carriage (MC) moves the specimen in and out of the flame at times pre-set on automatic timing devices (T), triggered from a switch (SW) and relayed through solenoids (S). A radiometer (RAD) is mounted behind an automatically-operated shutter (RS) which is synchronized with the variable carriage to open immediately on positioning of the specimen in the flame. To protect the radiometer from the convection currents

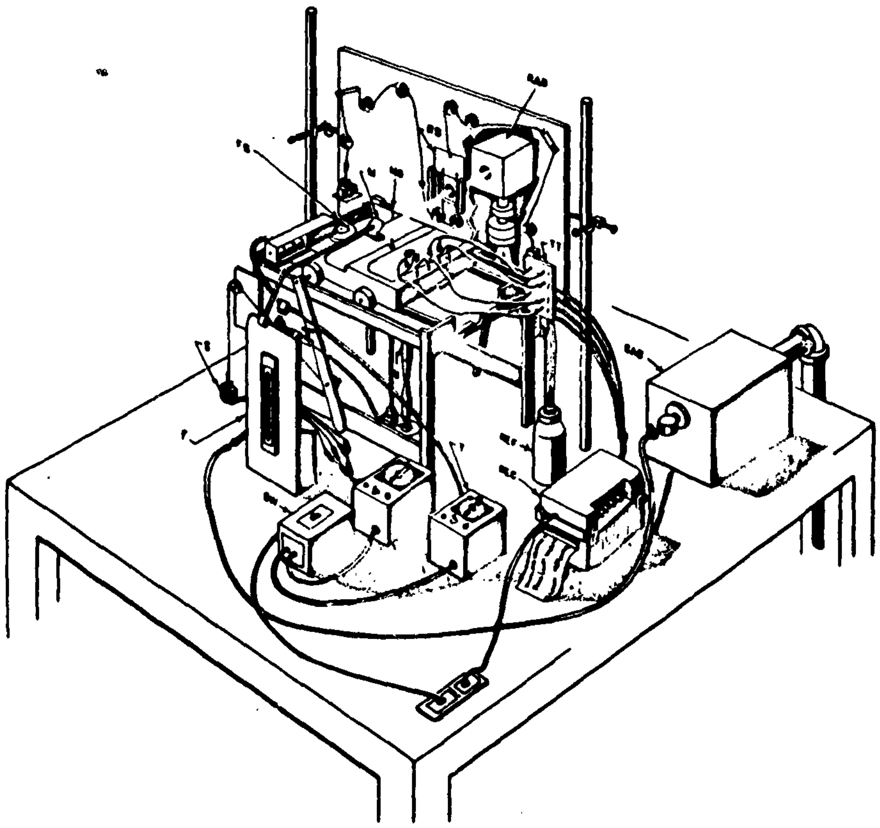

Figure 1. Flame contact apparatus (see text for explanation).

of the flame, should they pass through the specimen, a front surface mirror (M) is mounted over the specimen at a 45^{o} angle to the radiometer. To protect the radiometer from exposure to the full flame of the burner, a flame-shield (FS) is provided which is automatically actuated by one of the timers to snap into place over the flame just prior to the automatic removal of the specimen from the flame. Used with a filter to block any visible wavelengths, the radiometer provides measurements of the radiant temperature of the back surface of the specimen during flame-contact with the front surface. In addition, thermocouple terminals (TT) are provided so that thermocouples may be placed in any location desired. The cold junctions are immersed in a thermos bottle (REF) at 0^{o}C. The outputs from the thermocouples and the radiometer are fed into the recording oscillograph (REC).

Various holders may be mounted on the carriage for special purposes. Thus, for single layers of fabric a flat plate (Fig. 2A) is used; for exposures of anaesthetized rats, a cradle type (Fig. 2B); for materials applied to simulated skin, a curved plate (Fig. 2C), and for assemblies of double layers of fabric separated by air spaces of pre-set thicknesses and applied to the simulated skin device, a series of curved plates (Fig. 2D) which are inserted between the simulated skin section and its base plate.

A thermocouple attached to the base plate of the carriage monitors the temperature of the flame to assure reproducibility of the heat supply from one exposure to another. In this measurement, equilibrium conditions do

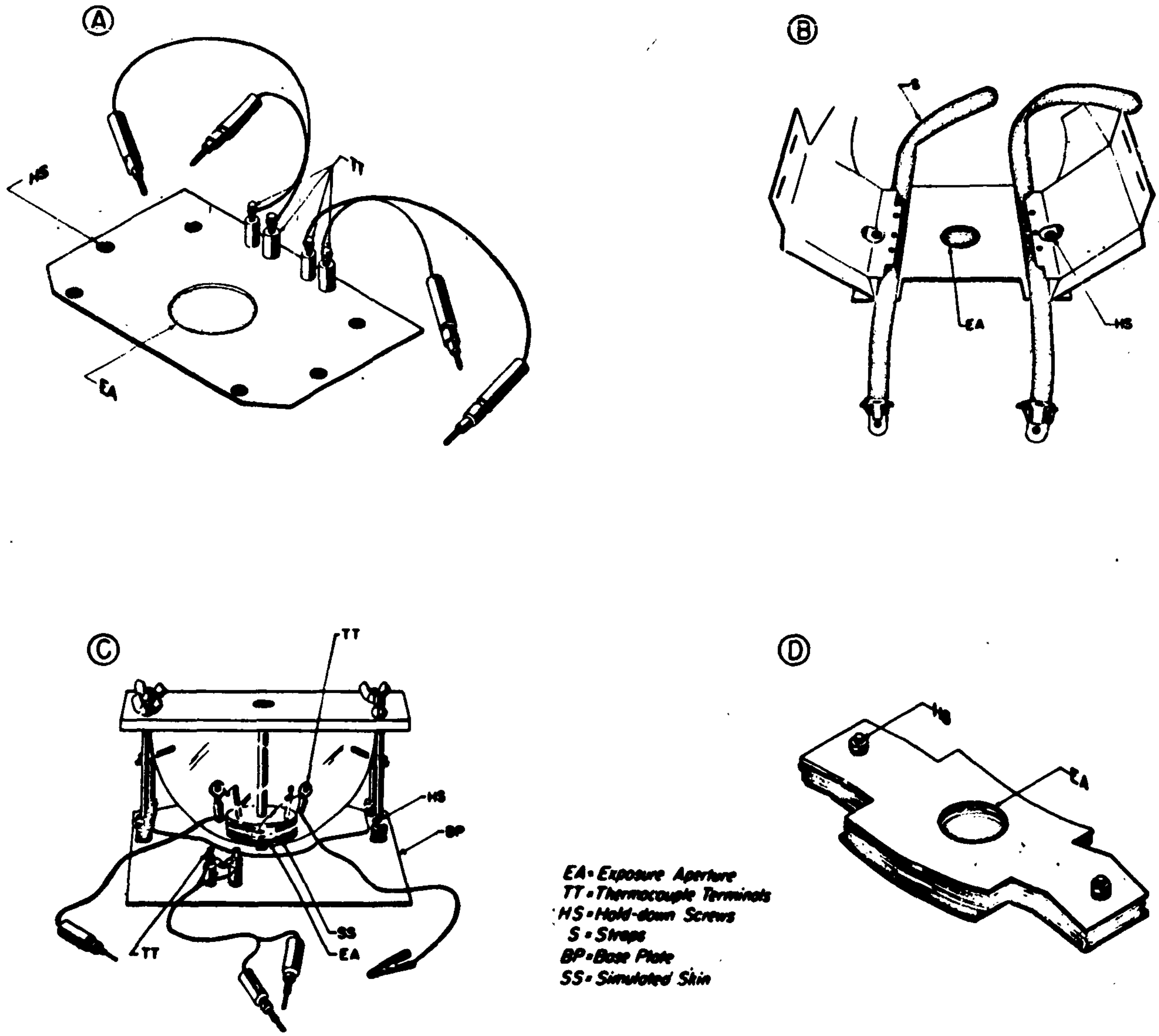

Figure 2. Mounting plates.

not pertain; instead, the thermocouple output is correlated with exposure time so that reproducibility is indicated by reproducibility in deflection magnitude at a given time even though this deflection does not provide instantaneous flame temperature.

In order to obtain experimental data that would be suitable for rigorous mathematical analysis, it was necessary to provide a backing for the test material which would permit accurate temperature measurements at a known depth and which would have accurately-known thermal properties. The simulated skin device developed by the Naval Material Laboratory (NML), New York (2, 3) fits these requirements precisely. It is composed of a resinous compound of carefully determined thermal and optical properties and provides accurate measurements of temperature within the compound at a depth of 0.5 mm from the surface of a section about 1 cm thick. A number of these devices were contributed by NML for this study and all the data on temperature measurements in depth reported in this work were obtained with the help of these instruments.

EXPERIMENTAL RESULTS AND DISCUSSION

Prior to the initiation of the study of fabric effects, it was advisable to determine the flame temperature and to set the gas flow at a rate such that an adequate surface of the test material would be heated evenly.

The method of progressively thinner wires as used by H. Schmidt (4) was employed for measurement of the flame temperature and, as shown in Fig. 3, it was determined to be 1200°C.

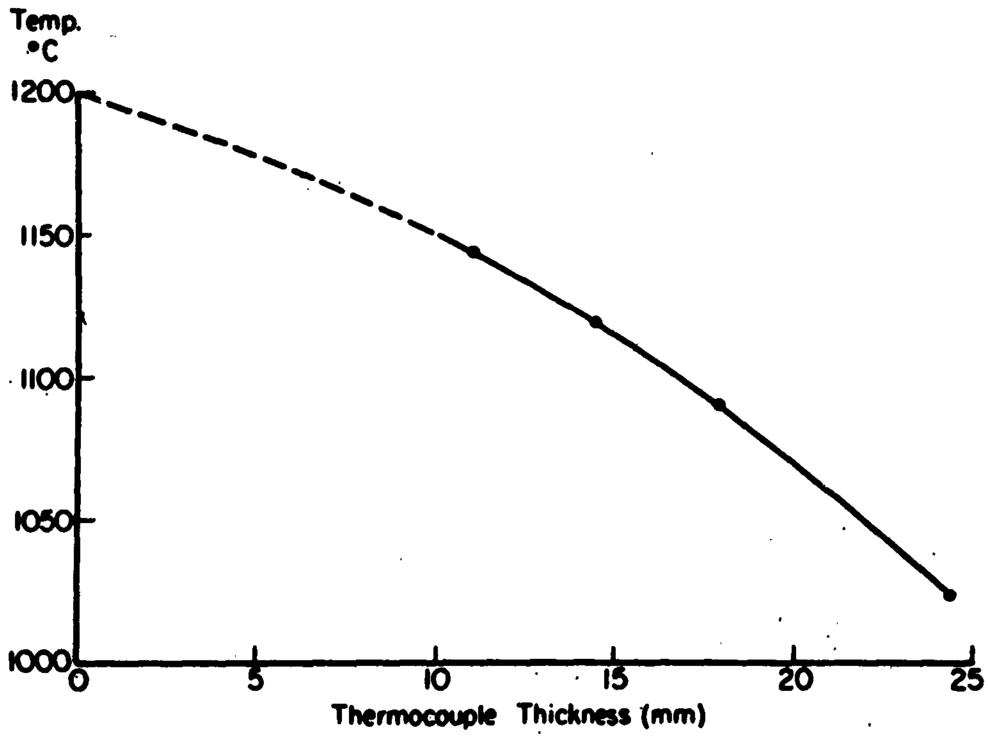

Figure 3. Flame temperature.

Routinely, the gas flow was set at 325 cc/min which provided a steady flame in contact with the surface of the specimen at a height of 3 cm above the surface of the burner. In studying multiple layers, it was necessary to double the flow rate to maintain a steady flame at the surface of the second layer, approximately 4 cm above the burner surface.

In conducting an exposure, the routine procedure was to: (1) affix the specimen in place with the appropriate mounting plate and associated measuring and recording equipment, (2) set the timing devices as desired, (3) set the gas flow, (4) start the recorder, and (5) trigger the main switch. The spécimen was moved into the flame and out again at the pre-set time and the flame was turned off manually. The record provided simultaneous measurements of time, start of flame contact, end of flame contact and all temperatures desired.

From the data so obtained, it was possible to determine directly the destruction temperature of the fabric, its resistance to heat transfer and the insulation effect of air spaces between layers. By application of appropriate mathematical analysis to the temperature-time histories, thermal conductivity of the fabric, interface temperatures at the point of contact with the backing material and surface temperature at the point of contact with the flame may also be determined (5). These latter considerations are lengthy and are contained in a separate report. The present observations, made on fabrics of a new heat-resistant, synthetic fiber, Du Pont experimental HT-1, serve to illustrate the immediate application of the experimental data.

Destruction Temperature. These measurements were made on the back of single layers of fabric in contact with the flame until the flame broke through the fabric. Fig. 4 illustrates the determination of the destruction temperature radiometrically. The average value for fabrics of 3, 4, 5, and 6 oz/yd^2 weight was 427 ± 3°C. The same temperature determined by fine (B & S gauge #40) thermocouples attached as closely as possible to the same surface was 423 ± 27°C. The wide range of the values obtained by the latter method is undoubtedly due to variability in the contact of the thermocouple with the fabric surface. However, these measurements indicate that where accuracy better than ± 10% is not required, the radiometric measurements may be eliminated.

Heat Transfer Resistance. Comparison of the temperature rise measured in the backing material and that of the backing material covered by known thicknesses of fabric yields an indication of the resistance to heat transfer offered by the material. As shown in Fig. 5, where temperature rise within the backing, measured at 3 seconds after flame contact, is plotted against thickness, even very thin layers are highly effective in reducing heating during this period of time. If desired, this effect may be correlated directly with fabric thickness yielding an empirical relationship useful throughout the range of thicknesses studied. As the thickness increases, the effect of the thermal properties of the backing material

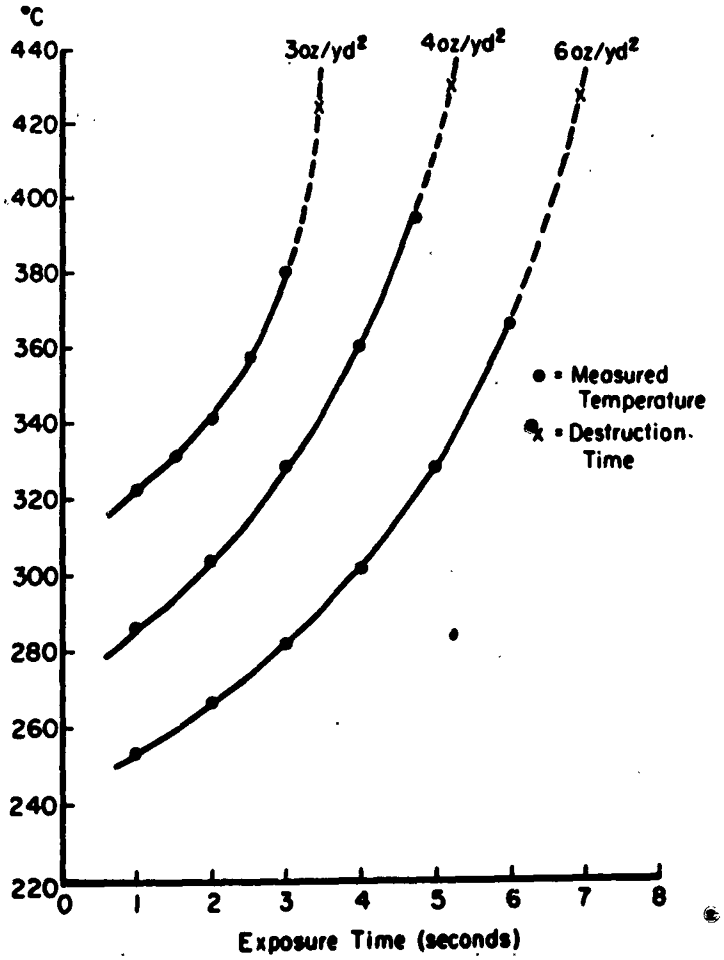

Figure 4. Radiometric measurement of destruction temperature.

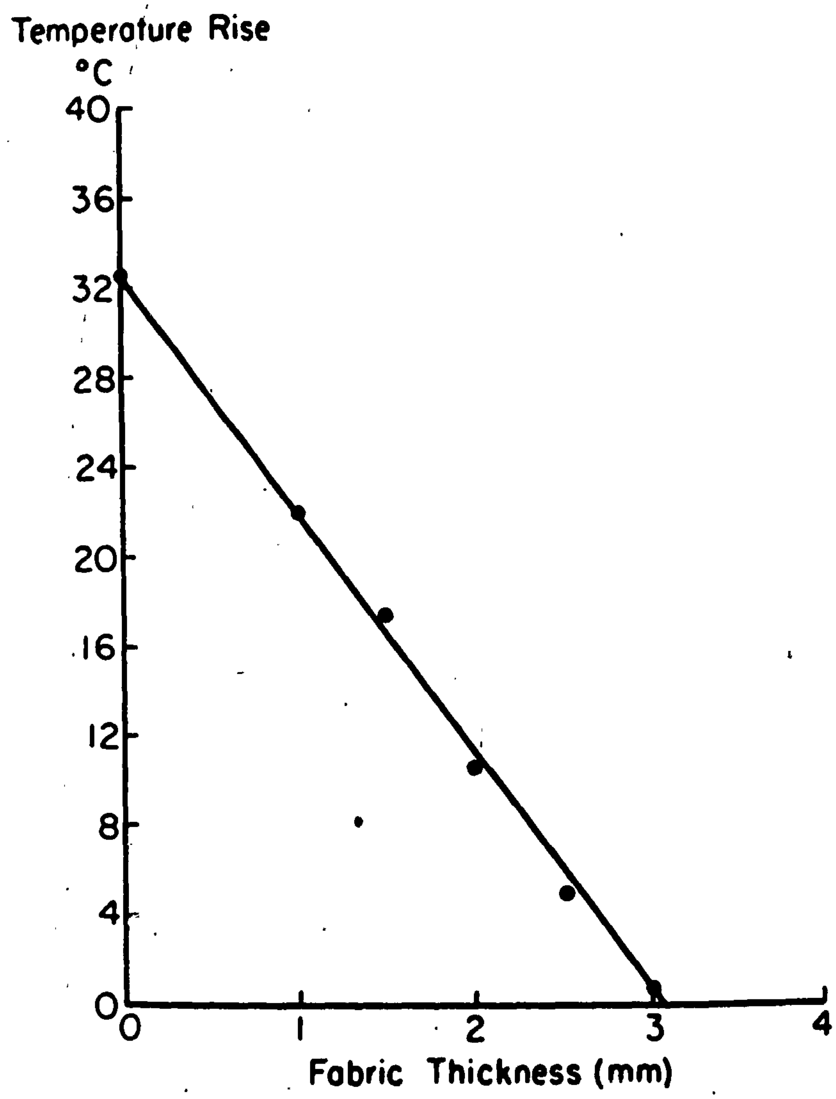

Figure 5. Temperature rise within simulated skin vs. thickness of fabric applied.

diminishes. The determination of "critical thickness" (that thickness beyond which the assembly in a given exposure time behaves like a homogeneous layer) may be measured directly in a series of exposures or may be computed (5). However, "critical thickness" applies only to single layers, for it was found that with two layers of fabric in contact with each other, on exposure to the flame, the layer in contact with the flame bulged out from the underlayer, created an air space and so protected the second layer. Thus, two layers of 3 oz/yd^2 fabric, with no deliberate air space between them, remained physically intact after flame contact for over 4 minutes whereas a single layer of 6 oz/yd^2 material of the same fiber burned through in 7.5 seconds.

Insulation Effect of Air Spaces. The insulation effect of deliberately set air spaces is illustrated in Fig. 6 where the temperature rise measured within the backing at a given exposure time is plotted against the thickness of the air space between 2 layers of 3 oz/yd^2 fabric. This process discloses that there is an optimal thickness of air space which results in the greatest insulation effect. Beyond this thickness, heat transfer is enhanced indicating that convection currents arise and contribute to the propagation of the flame front through the fabric causing it to perforate. At this point, of course, the flame reaches the second layer of fabric, the integrity of the assembly is destroyed, and it then behaves like a single layer. That this effect applies equally well to the clothed skin situation is illustrated in

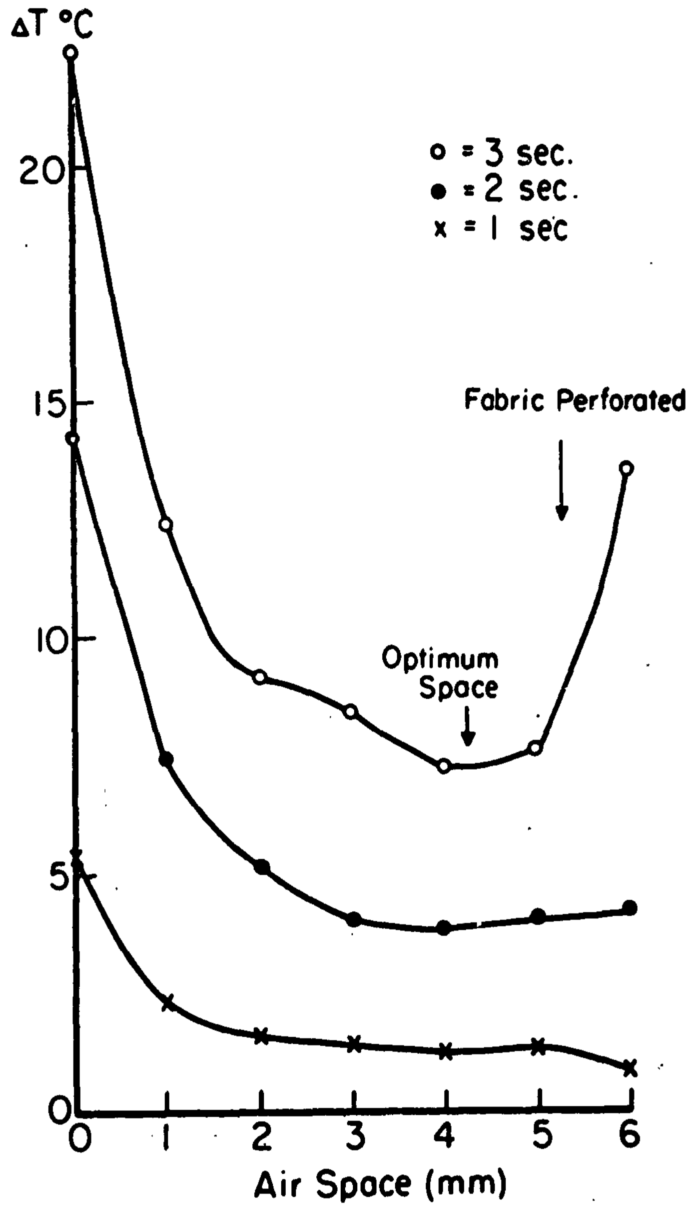

Figure 6. Temperature rise within simulated skin vs. thickness of air space between two layers of 3 oz/yd^2 fabric.

Fig. 7 which shows the protection provided in terms of time required to produce a standard white burn in rat skin as the air space was increased. With a two-layer assembly under which a white burn was produced in 2 seconds in the absence of an air space, incorporation of air spaces provided increased protection to a maximum of 5.5 seconds. Thereafter, the outer layer perforated and protection decreased. Again, the optimal space was about 4 mm as found with this assembly on the simulated skin device.

CONCLUSION

It is concluded that the apparatus and system described herein provide a simple and rapid means of obtaining experimental data in flame contact studies. They are applicable to direct determinations of destruction temperatures, heat transfer resistance of the material, and the insulation effect of air spaces between layers of the material. The empirical results imply that multiple layers separated by relatively small air spaces would provide the most effective insulation in short-term, high temperature flame contact. In addition to providing empirical data, the experimental arrangement is so designed that the observed data are amenable to rigorous mathematical analysis.

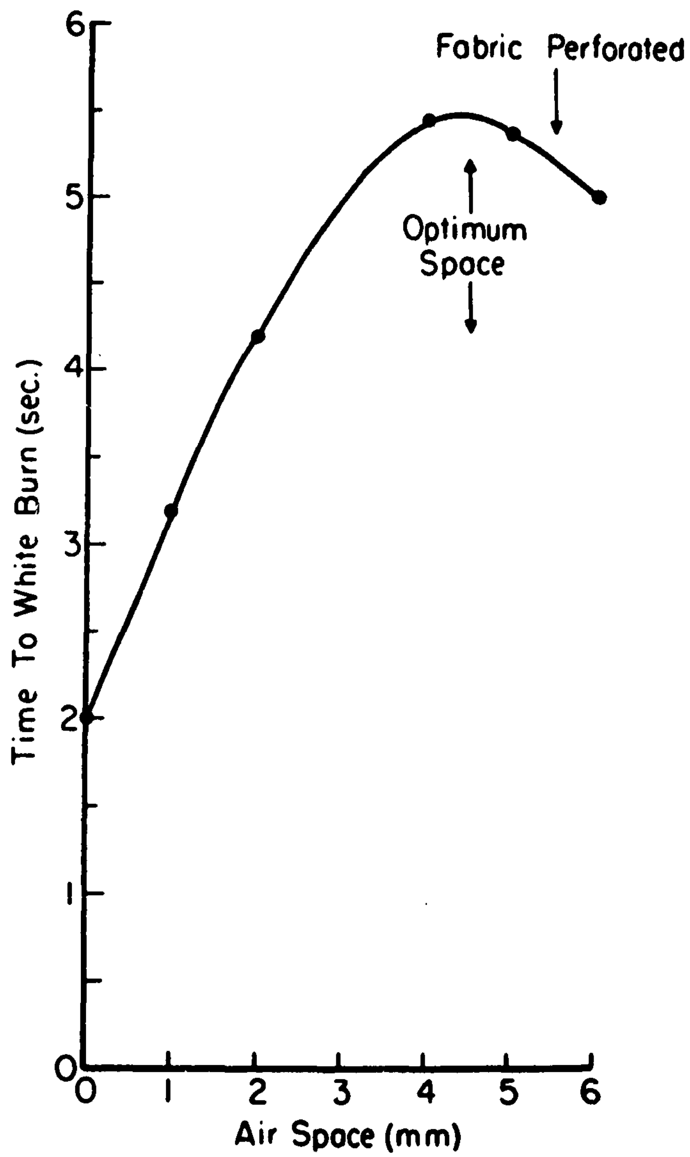

Figure 7. Exposure time productive of ~~white~~ burn in anaesthetized, depilated rat vs. thickness of air space between two layers of 3 oz/yd^2 fabric.

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